Copeland Corporation

Co-Rotating Scrolls for Air-Conditioning Systems

The heating, ventilation, and cooling industry faced radical changes in the 1990s. The phase-out of environmentally damaging refrigerants, growing demand for air-conditioning in developing countries, and U.S. consumers' desire for energy-efficient machines all led U.S. manufacturers to seek new technology. Both European and Asian companies were meeting this demand, while their U.S. counterparts risked being frozen out of the market. Specifically, manufacturers were looking at ways to develop variable-speed, smaller, quieter compressors for residential air-conditioners and heat pumps, with the promise of greater energy efficiency and cost effectiveness.

Copeland Corporation, a manufacturer of compressors and heat pumps, had been an early adopter of the orbiting-scroll compressor, which had significantly advanced the efficiency of air-conditioners and heat pumps. By the mid-1990s, Copeland was exploring the use of the co-rotating scroll after technical breakthroughs had made its development feasible. The company's research was high risk because the materials and manufacturing processes for the new scroll had yet to be validated and because lowering noise and vibration at high speed had never been done. The company applied to the Advanced Technology Program (ATP) in 1995 through the "Advanced Vapor Compression Refrigeration Systems" focused program and was awarded cost-shared funds that same year. In developing the co-rotating scroll technology, the company would also be investigating switched-reluctance motor-drive technology, which would lead to still smaller, quieter units. In addition, the project would look at lighter weight alternatives to cast iron for the compressor housing.

By the conclusion of the three-year project, Copeland had achieved some of its objectives, but the co-rotating scroll proved to work no better than existing systems for the small capacities for which it was intended. However, as efficiency ratings become more stringent, Copeland is looking again at the technologies developed during this project. The growing hybrid automobile market, for example, is increasing the demand for lighter metal composites in embedded systems such as electricity-driven air-conditioning. If larger volume compressors prove cost effective, Copeland could again consider the co-rotating scroll. The company holds two patents on composite aluminum scroll components stemming from the project.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)

No Stars

Research and data for Status Report 95-06-0022 were collected during July – August 2005.

Industry Looks for More Efficient Compressors

In a 1993 white paper, the Air Conditioning and Refrigeration Institute (ACRI) proposed that ATP co-sponsor a major initiative to keep the U.S. industry competitive. U.S.-made systems, which accounted for 40 percent of the global market, were being displaced. Japan also had 40 percent of the market, and other Asian countries and Europe were quickly increasing their market share, having developed small and quiet compression technologies for low- and medium-capacity systems. The white paper stated that the proposed program could increase the average energy efficiency of air-conditioning, save billions of dollars in energy costs, and significantly reduce air pollution. To achieve these goals, the U.S. industry needed to nearly

double the seasonal energy efficiency ratio (SEER) of residential air-conditioners and heat pumps from an average of 10.5 to 20. According to the white paper, cost-effectively achieving a SEER of 20 "will require an impressive effort and will revolutionize the [air-conditioning and refrigeration] market."[1] Furthermore, there were indications that the Department of Energy would tighten its SEER requirements by 2000.

In response, ATP developed the "Advanced Vapor Compression Refrigeration Systems" focused program in 1995 with industry support. Its goals included a 25-percent increase in the SEER with reduced noise levels and component size.

At that time, the U.S. air-conditioning industry was focused on central air-conditioners that used fixed-speed compressors with two settings. Variable-speed motors were available, but their high cost lowered their appeal. The ACRI said manufacturers needed to cut the motor systems' costs by half to be attractive to consumers. Japanese manufacturers had marketed a one-horsepower compressor and foresaw a market for variable-speed compressors; these components were scaled to a size that could have been a threat to the U.S. market, but they were not produced in large quantities. Among the improvements the U.S. industry sought were cost-effective, affordable, high-efficiency motor systems that would be a major step toward highly efficient equipment.

Scroll compressors, which have been standard in air conditioning and refrigeration since the mid-20th century, consist of two spiral leaves, or scrolls (see Figure 1). One scroll orbits around a second fixed scroll, trapping and compressing pockets of fluid as it moves. Scroll compressors used in air-conditioners traditionally have only a few moving parts, including a scroll that orbits within a stationary scroll to compress the refrigerant. The orbiting scroll compresses gas by moving one scroll against a fixed scroll around a common axis. The scroll compressor had been made possible when computerized numerical-controls manufacturing was introduced. Copeland Corporation, a manufacturer of compressors and heat pumps, adopted the orbiting-scroll compressor before other companies. These compressors gained popularity because of their higher efficiency, lower noise and vibration, and versatility. However, at high speeds these compressors were noisy and became unbalanced.

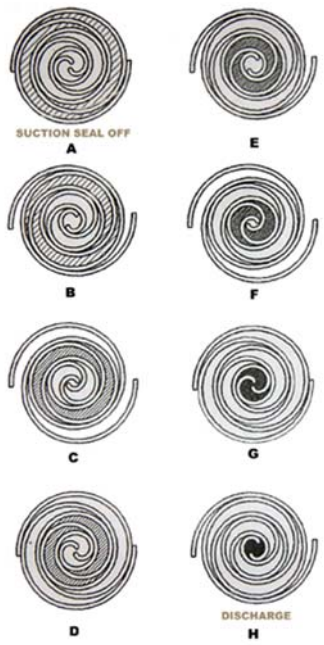

Figure 1. Orbiting Scroll Compression Process (Purvis 1987)

Copeland wanted to improve compressor efficiency, but candidates to replace the technology could not be developed in the near term and thus did not fall within the scope of research that Copeland would fund on its own.

Co-rotating Scroll Attracts Attention

Copeland was particularly interested in a co-rotating design in which both scrolls rotate. The design had been patented in the 1920s but had never been commercialized. This type of scroll seemed to allow variable speeds and higher speeds, using a smaller motor and smaller displacement scroll. In 1995, Copeland applied to ATP through the "Advanced Vapor Compression Refrigeration Systems" focused program for cost-shared funding to develop the co-rotating scroll, build a prototype, and test it. They planned to develop new materials and manufacturing processes for the scroll elements, perfect techniques to lower sound and reduce vibration at high speeds, and develop a switched-reluctance drive motor. Copeland received an award for a three-year project, which began the same year.

1. Air Conditioning and Refrigeration Institute. "Innovative Air-Conditioning and Refrigeration Research: Meeting Global Opportunities," White Paper to NIST/ATP, December 10, 1993.

Co-rotating scroll technology was a way to scale up to bigger size," said Wayne Warner, research planner for Copeland. That is, a compressor with a co-rotating scroll could run a larger refrigeration system than the same size compressor with a conventional orbiting scroll. Alternatively, the co-rotating scroll could allow manufacturers to make smaller compressors to run more compact systems, he added.

Although the company originally proposed to test a compressor with a three-ton cooling capacity, with ATP's approval Copeland changed the scope before the project began to test a two-ton compressor, which presented more challenges and, if successful, would be even more efficient. The project aimed to achieve heat pump compressor speeds three times faster for cooling and four times faster for heating than the speeds of other compressors on the market. At half the height and an inch less in diameter, the new compressor would take up half the volume and improve energy efficiency by 25 percent. If successful, the motor would emit 68 decibels at high speed, compared to a noise level of 80 decibels at high speed for standard compressors. The new scroll would cost the same as competing variable-speed compressors.

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In the first two years of the project, Copeland completed the design, assembly, and testing of prototypes for horizontal variable-speed co-rotating scroll compressors. The horizontal design was an innovation; instead of a mechanical pump, the design used a pressure delivery system to drive the oil where it was needed within the compressor. Sound tests indicated that the horizontal design was 1.6 decibels (25 percent) quieter than the conventional vertical scroll used with a mechanical oil pump. The team analyzed and tested scroll elements, pressure balancing and bearing structures, bearing size, static force, seal requirements, and rate of feed for the lubricant. If progress continued, the company said, in the final year of the program they would develop the full compressor design and integrate it with other components of the air-conditioning system to produce maximum efficiency and performance.

Motor and Scroll Tests Are Disappointing

In the final year of the ATP-funded project, however, the co-rotating scroll proved less reliable than orbiting scrolls for compressors of two- to five-ton capacity. For these sizes, the company found it could achieve the desired speed ratio with the orbiting scroll. The company concluded that the co-rotating scroll would have more merit in larger units, such as 20-ton compressors, but these sizes were not being built. Copeland instead chose to cool large spaces by using several smaller compressors.

Tests also ruled out the switched-reluctance motor, which made too much noise. Copeland determined that the motor was best suited for tractors and generators, for which noise reduction is not an issue. To damp excess noise, compressors in these applications could use sound blankets.

Copeland began to develop new composite metals with the University of Wisconsin. To make higher speeds possible, their research centered on aluminum metal-matrix composites to provide a lighter alternative to the cast iron used in the compressor housing. The work revealed that the lighter material had no advantage for fixed-speed compressors, where weight was not a concern; cast iron was acceptable and much more cost effective than aluminum composites. In July 1998, Copeland joined the Air Conditioning and Refrigeration Center Industry-University Cooperative Research Center at the University of Illinois and began bench testing how well the aluminum metal matrix composite resisted surface damage and wear. They also worked on refrigerant composition with the Center for Environmental Energy Engineering at the University of Maryland.

Further Development Is Needed

At the end of the project in September 1998, Copeland said it needed to further develop the aluminum metal-matrix composite for use in variable-speed motors, the casting process, the machining process to manufacture the scroll elements, and proof of compressor performance and reliability. They also needed to demonstrate that the refrigerant did not carry oil away from the compressor in the pressure-delivery system and needed to resolve the trade-off between efficiency and sound level in the variable-speed motor. The

company planned to continue research on each of these topics for two to three years. The two patents to emerge from the project were both for composite aluminum alloy scroll machine components.

Speed to market was important in Copeland's ability to achieve its business goals. With significant competition from Europe and Asia, the company gauged its window of opportunity to market a product within five years following the end of the project. The company planned to continue research on key topics for two to three years and invested $250,000 in this research. But Copeland took no steps to commercialize the co-rotating scroll compressor and, saying it continued to face significant technical barriers, decided to postpone commercialization indefinitely. In August 2004, Copeland reported that a competing technology using a digital orbiting scroll had achieved the technical goals set by the ATP project and did not have the co-rotating scroll's disadvantages. In 2005, Copeland entered the Asian market through a joint venture with Lennox and Trane to build compressors using this new non-ATP-funded technology at a plant in Thailand.

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Copeland continues to look into commercial possibilities for horizontal and variable-speed scrolls. As energy-efficiency ratings become more stringent, U.S. consumers are looking for more efficient ways to heat and cool their homes, such as the systems used in Europe and Asia. That could cause Copeland to renew their interest in co-rotating scroll compressors. With growing demand for the kind of hybrid vehicles that require an electricity-driven compressor when the engine is not running, Copeland is looking at a motor with a blanket on the hood of the engine that deadens sound.

ATP Helped with Collaboration and Materials Research

Copeland credits ATP with getting them started in collaborating with others, and after the project ended, they entered into other collaborative efforts. "The ATP project helped us get outside of our comfort zone," said Warner. "We started doing more research in conjunction with universities, and we've entered into joint ventures. In addition, we became more attentive to our ultimate customers, not just to the original equipment manufacturers that used our components. Before ATP we had principally talked to the original equipment manufacturers," he added.

In addition, Warner said, the ATP project furthered development of the horizontal configuration and led to a variation of the configuration in two other products, a natural gas booster scroll compressor and a glacier refrigeration scroll. Copeland increased its knowledge of alternatives to cast iron and other useful but less durable materials, and it took a new approach in evaluating them. "Research is sometimes finding the path you don't want to go down; in the case of this project, that was switched-reluctance [motors] and, for small sizes, the co-rotating scroll. But the techniques we used in developing materials are incorporated in our practice now," said Warner.

Conclusion

Copeland Corporation, a manufacturer of compressors and pumps for the air-conditioning and refrigeration industry, was interested in developing a co-rotating compressor scroll that would be smaller, quieter, and more efficient than the orbiting-scroll compressor it had used for many years. The company developed a co-rotating scroll compressor technology, which involved a switched-reluctance variable-speed motor, horizontal placement of the scroll, and new materials for the compressor housing. Testing revealed that the horizontal scroll had advantages, but neither the motor nor the metal composite offered any improvements over orbiting-scroll compressors for the size of the air-conditioner for which it was designed.

After ATP funding ended, Copeland pursued independent research on the motor system and composites, but ultimately abandoned the technology. Copeland did make use of the metal matrix composites and variable speed motors developed during the project, along with methods from the ATP project in research and development that led to commercialized products. The company also holds two patents on the scroll technology.

PROJECT HIGHLIGHTS
Copeland Corporation

Project Title: Co-Rotating Scrolls for Air Conditioning Systems (High- and Variable-Speed Co-Rotating Scroll)

Project: To develop high- and variable-speed co-rotating scroll compressor technology powered by a switched-reluctance motor/drive system for use in small, quiet residential cooling and heat pump units.

Duration: 9/15/1995 - 9/14/1998
ATP Number: 95-06-0022

Funding (in thousands):

ATP Final Cost	$1,296	64.5%
Participant Final Cost	712	35.5%
Total	$2,008	

Accomplishments: With ATP funding, Copeland Corporation accomplished the following:

- Invented a horizontal design that replaced a mechanical pump with a quieter pressure delivery
- Initiated aluminum metal matrix composite research and development (R&D) and furthered R&D in co-rotating scroll compressor technology

Copeland Corporation received the following patents for technologies related to the ATP-funded project:

- "Composite aluminum alloy scroll machine components "
  (No. 6,079,962: filed March 25,1997, granted June 27, 2000)
- "Composite aluminum alloy scroll machine components "
  (No. 6,401,796: filed May 2, 2000, granted June 11, 2002)

Commercialization Status: Copeland elected not to commercialize the technology when it proved no more cost effective than the compressors already on the market.

Outlook: Most of the technology developed under this project has been superseded by the digital orbiting scroll compressor. However, Copeland continues to look into uses for the switched-reluctance motor and aluminum metal matrix composites for the compressor housing. The co-rotating scroll could be cost effective on very large systems, but to date the company has used a complement of smaller systems to achieve the same cooling capacity.

Composite Performance Score: No Stars

Focused Program: Advanced Vapor Compression Refrigeration Systems, 1995

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